

METHOD OF PRODUCING CATHODE MATERIAL
FOR LITHIUM SECONDARY CELL

TECHNICAL FIELD

The invention relates to a method of producing a cathode material for a lithium secondary cell, capable of contributing to enhancement in cell performances such as initial capacity, cycle characteristics, safety at high temperature, and so forth.

BACKGROUND TECHNOLOGY

There has lately been seen a further step-up in intensity in the race for developing a lithium secondary cell, which is regarded as a cell having excellent properties with respect to energy density while exhibiting a high discharge voltage.

The lithium secondary cell is comprised of three basic elements, namely, a cathode, an anode, and a separator retaining an electrolyte interposed between the cathode and the anode.

For the cathode and the anode, among those elements, use is made of "a slurry prepared by mixing, and dispersing an active material, an electroconductive material, a binding agent, and a plasticizer, where necessary, into a dispersion medium", applied to a current collector, such as a metal foil, metal mesh, and so forth.

As an active substance applied to the cathode, among those elements, there have been known a lithium-cobalt oxide complex ($\text{Li}_x\text{CoO}_2 : 0 \leq x \leq 1$), a lithium-manganese oxide complex ($\text{Li}_x\text{Mn}_2\text{O}_4 : 1.0 \leq x \leq 1.2$) and so forth.

Meanwhile, for an active substance applied to the anode, use is generally made of a lithium foil, and a material capable of occluding / evolving lithium ions (a carbon material such as, for example, a coke-based carbon, and a graphite-based carbon).

For the electroconductive material, use is made of a material having an electron conductivity (for example, natural

graphite, carbon black, acetylene black, and so forth) and for the binding agent, use is generally made of a fluororesin such as polytetrafluoroethylene (PTFE), poly(vinylidene fluoride) (PVDF), hexafluoropropylene (HFP), and so forth, and a copolymer thereof.

For the dispersion medium, use is made of an organic solvent capable of dissolving the binding agent, such as, for example, acetone, methyl ethyl ketone (MEK), tetrahydrofuran (THF), dimethyl formamide, dimethyl acetamide, tetramethyl urea, trimethyl phosphate, N-methyl-2-pyrrolidone (NMP), and so forth.

As the plasticizer to be added as necessary, an organic solvent that can be replaced with the electrolyte after a film is formed by applying the slurry to the current collector is suitable, and a diester phthalate is preferably used.

Then, for the current collector to which the slurry is applied, use is generally made of a copper foil or an aluminum foil.

Further, the slurry necessary for application to the current collector is adjusted by kneading and mixing the above-described active material, electroconductive material, binding agent, dispersion medium, and plasticizer at a predetermined mixing ratio, and various application methods such as gravure coating, blade coating, comma coating, dip coating, and so forth can be adopted for application of the slurry to the current collector.

As the electrolyte to be retained by the separator, there has been known a liquid-based electrolyte, a polymer-based electrolyte, or a solid-based electrolyte, however, the liquid-based electrolyte composed of a solvent and a lithium salt dissolvable in the solvent is in widespread use. An organic solvent selected from the group consisting of polyethylene carbonate, ethylene carbonate, dimethyl sulfoxide, butyrolactone, sulfolane, 1,2-dimethoxyethane, tetrahydrofuran, diethyl carbonate, methyl ethyl carbonate, dimethyl carbonate, and so forth is regarded as suitable for use as the solvent in

this case, and any selected from the group consisting of LiCF_3SO_3 , LiClO_4 , LiBF_4 , LiPF_6 , and so forth is preferable as the lithium salt.

Incidentally, the lithium-manganese oxide complex, lithium-cobalt oxide complex, and so forth, for use as the active material of the lithium secondary cell, are generally synthesized by mixing a compound (manganese oxide, cobalt oxide, and so forth), serving as the major component of a cathode material for a lithium secondary cell, with a lithium compound (lithium carbonate, and so on) at a predetermined mixing ratio before heat treatment is applied thereto.

Further, in order to cope with the requirements for enhancement in cell performance, it has recently been practiced to dope the cathode material for the lithium secondary cell, such as the lithium-manganese oxide complex, lithium-cobalt oxide complex, and so forth, with a small amount of another element (to be added to the former), in which case the cathode material for the lithium secondary cell is synthesized by mixing the compound (manganese oxide, cobalt oxide, and so forth), serving as the major component of the cathode material for the lithium secondary cell, the lithium compound (lithium carbonate, and so on), and a component (cobalt oxide, manganese carbonate, and so forth) of a dopant element, at a predetermined mixing ratio, thereby preparing a mixture, and by applying a heat treatment to the mixture.

However, because the requirements for enhancement in cell performance of the lithium secondary cell have since become increasingly severer, and in particular, a desire for further improvement in cell performance such as "initial capacity", "cycle characteristics", and further, "safety" to not allow the characteristics thereof to be impaired, even at a high temperature, has become stronger, a race in research for attainment of the above-described performance as required from the viewpoint of the cathode material has come to be intensified.

Under the circumstances, it is an object of the invention to provide a cathode material for a lithium secondary cell, capable of stably exhibiting further excellent cell performance with respect to initial cell capacity, cycle characteristics, and safety.

DISCLOSURE OF THE INVENTION

To that end, the inventors have continued extensive studies and, as a result, have succeeded in obtaining the following knowledge. That is, when doping a cathode material for a lithium secondary cell, such as a lithium-manganese oxide complex, lithium-cobalt oxide complex, and so forth, with another element in order to improve the performance of the cell, if a doping method is adopted whereby a compound of a dopant element is first precipitated and bonded on the surface of "a compound of a metal, as the major component of a cathode material for a lithium secondary cell, in powdery form, by use of a chemical method, and subsequently, "the compound of the metal, as the major component of the cathode material for the lithium secondary cell", after being treated as above, is mixed with a lithium compound, such as lithium carbonate, and so forth, to be subsequently fired, instead of using a conventional method of mixing fine powders of the compound of the dopant element, such as cobalt oxide, manganese carbonate, and so forth, with powders of "the compound of the metal, as the major component of the cathode material for the lithium secondary cell", such as manganese oxide, cobalt oxide, and so forth, thereby firing a mixture, it becomes possible to stably obtain a cathode material for implementing a lithium secondary cell exhibiting excellent initial capacity, cycle characteristics, and safety.

The invention has been developed based on the above-described items of knowledge, and so forth, providing a method of producing a cathode material for a lithium secondary cell, as shown under the following items 1 through 7:

(1) A method of producing a cathode material for a lithium secondary cell, comprising the steps of preparing a solution selected from the group consisting of an alkaline solution, a carbonate solution, and a hydrogencarbonate solution, with a compound of a metal, as the major component of a cathode material for a lithium secondary cell, suspended therein, dripping an aqueous solution of a salt of another element into the solution, precipitating a compound of the other element on the surface of the compound of the metal, as the major component, subsequently preparing a mixture by mixing the compound of the metal, as the major component, with the compound of the other element, precipitated and bonded thereon, with a lithium compound, and firing the mixture.

(2) A method of producing a cathode material for a lithium secondary cell as in the item 1 above, wherein the metal in the compound of the metal, as the major component, is an element selected from the group consisting of elements Co, Mn, and Ni.

(3) A method of producing a cathode material for a lithium secondary cell as in the item 1 or 2 above, wherein the other element is at least one element selected from the group consisting of transition metals (Sc, Ti, V, Cr, Mn, Fe, Co, Ni, and Cu), alkaline metals (Li, Na, K, Rb, Cs, and Fr), alkaline earth metals (Be, Mg, Ca, Sr, Ba, and Ra), B, and Al.

(4) A method of producing a cathode material for a lithium secondary cell as in any of the items 1 to 3 above, wherein the ratio of the metal in the compound of the metal, as the major component, to the other element is in a range of 99:1 to 40:60 in terms of a mole ratio.

(5) A method of producing a cathode material for a lithium secondary cell as in the item 1 or 4 above, wherein the metal in the compound of the metal, as the major component, is the element Mn and the other element is at least one element selected from the group consisting of Co, Ni, Al, Mg, and Ti).

(6) A method of producing a cathode material for a lithium secondary cell as in the item 1 or 4 above, wherein the metal in the compound of the metal, as the major component, is the element Co and the other element is at least one element selected from the group consisting of Mn, Ni, Al, Mg, and Ti).

(7) A method of producing a cathode material for a lithium secondary cell as in the item 1 or 4 above, wherein the metal in the compound of the metal, as the major component, is the element Ni and the other element is at least one element selected from the group consisting of Co, Mn, Al, Mg, and Ti).

BEST MODE FOR CARRYING OUT THE INVENTION

As "a compound of a metal, as the major component of a cathode material for a lithium secondary cell", there can be cited a compound such as a metal carbonate, and a metal hydroxide, besides a metal oxide such as, for example, a cobalt oxide as the major component of a lithium-cobalt oxide complex-based cathode material for a lithium secondary cell, manganese oxide as the major component of a lithium-manganese oxide complex-based cathode material for a lithium secondary cell, and nickel oxide as the major component of a lithium-nickel oxide complex-based cathode material for a lithium secondary cell. Further, use may be made of a hydroxide and an oxide, produced by the coprecipitation method.

In this connection, as the manganese oxide described, a manganese oxide under 10 μm in average grain size, obtained by applying oxidation treatment to "manganese carbonate produced by blowing carbon dioxide into aqueous ammonia of metallic manganese", as disclosed in, for example, JP-A 2000-281351, which is in Japanese Unexamined Patent Publication, can be suitable for use.

As an alkaline solution in which "the compound of the metal, as the major component of the cathode material for the lithium secondary cell" is to be suspended, there can be cited

an aqueous solution of lithium hydroxide, aqueous solution of sodium hydroxide, aqueous solution of potassium hydroxide, and so forth. A carbonate solution, for use in the same application, includes an aqueous solution of sodium carbonate an aqueous solution of potassium carbonate, and so forth, while a hydrogencarbonate solution includes an aqueous solution of sodium hydrogencarbonate, aqueous solution of potassium hydrogencarbonate, and so forth. Further, use can be made also of an aqueous solution of lithium hydrogencarbonate prepared by blowing carbon dioxide into an aqueous solution of lithium carbonate.

Then, a salt of another element refers to a salt of a dopant metal element, deemed effective for improvement of characteristics, and more specifically, includes sulfates, nitrates, and chlorides, or organic salts, containing transition metals (Sc, Ti, V, Cr, Mn, Fe, Co, Ni, and Cu), alkaline metals (Li, Na, K, Rb, Cs, and Fr), alkaline earth metals (Be, Mg, Ca, Sr, Ba, and Ra), and B or Al.

With the invention, an aqueous solution of the salt of the other element is first dripped into a solution in which the compound of the metal, as the major component of the cathode material for the lithium secondary cell, is suspended, thereby causing a compound of the other element to precipitate on the surface of the compound of the metal, as the major component, and at this point in time, the ratio of the metal in the compound of the metal, as the major component, to the other element is preferably rendered to be in a range of 99:1 to 40:60, in terms of mole ratio, whereupon various performances can be stably obtained.

Further, a lithium compound to be mixed with the compound of the other element precipitated and bonded on the surface of the compound of the metal, as the major component, to be subsequently fired is preferably lithium carbonate, which is heavily used for production of the cathode material for the lithium secondary cell, although not limited thereto, and the firing condition thereof may be the publicly known condition

applied for production of the cathode material for the lithium secondary cell.

As described in the foregoing, when doping the cathode material for the lithium secondary cell with Co, Mn, and so forth, in order to improve the performance of the cell, a method according to the invention does not adopt a conventional "method of mixing powders of a compound of a dopant metal with powders of a cathode raw material, thereby preparing a mixture, and firing the mixture". With the method according to the invention, a compound of the major component, in powdery form, such as the manganese oxide in the case of the lithium-manganese oxide complex-based cathode material, the cobalt oxide in the case of the lithium-cobalt oxide complex-based cathode material, the nickel oxide in the case of the lithium-nickel oxide complex-based cathode material, or so forth, is first suspended in an alkaline solution, carbonate solution or hydrogencarbonate solution (for example, aqueous solution of sodium hydrogencarbonate), and an aqueous solution of a salt of a dopant metal (the other element), such as cobalt sulfate, manganese sulfate, and so forth, is dripped in the described solution. As a result of such processing, cobalt carbonate, as the reaction product of the cobalt sulfate, is precipitated and bonded on the surface of, for example, manganese oxide particles as a compound of the major component, thereby obtaining the manganese oxide particles uniformly covered with the cobalt carbonate.

Subsequently, the compound of the major component covered with the compound of the dopant element (the other element) is mixed with a lithium compound (lithium carbonate, and so forth) before firing, whereupon there can be obtained a cathode material for a lithium secondary cell, doped with the other element, having a very high doping uniformity with a minimum ununiformity in doping.

With a lithium secondary cell to which the cathode material for the lithium secondary cell, produced by the method according to the invention, is applied, there can be

observed excellent initial capacity, cycle characteristics, and safety, capable of meeting severe requirements for enhancement in the cell performance of the lithium secondary cell.

The present invention is described hereinafter with reference to working examples.

Working Example 1

As a raw material of the major component of a cathode material for a lithium secondary cell, for production of the cathode material, use was made of manganese oxide 10 μm in average grain size, obtained by applying oxidation treatment to "manganese carbonate produced by blowing carbon dioxide into aqueous ammonia of metallic manganese in accordance with the method disclosed in JP-A 2000-281351 as previously described".

Subsequently, 1 kg of the manganese oxide described as above was suspended in 6 liters of aqueous solution of sodium hydrogencarbonate at 0.3 mole/l, and aqueous solution of cobalt sulfate at 0.22 mole/l was dripped in the former at a rate of 0.2 l/hr to undergo a reaction at room temperature for a predetermined time, and to be washed in water, thereby having obtained manganese oxide with the surface thereof, coated with cobalt carbonate.

With reference to the manganese oxide obtained after the above-described processing, it was confirmed by observation with an SEM (scanning electron microscope) and an EPMA (electron beam probe microanalyzer) that the surface of the manganese oxide was uniformly coated with the cobalt carbonate, and the mole ratio of Mn to Co was found to be 95:5.

Subsequently, after mixing lithium carbonate with the "manganese oxide coated with the cobalt carbonate" such that the ratio of $\text{Li}/(\text{Mn} + \text{Co})$ was 0.53, the obtained mixture was fired at 750°C in the atmosphere for 10 hrs, thereby obtaining a lithium-manganese oxide complex (LiMn_2O_4) doped with 5% of Co (this is referred to as material for Working Example 1).

The material obtained was 10 μm in average grain size, 0.4 m^2/g in specific surface area, and 2.1 g/cc in tap density. Further, the material was high purity, containing not more than 500 ppm of an alkaline metal represented by Na and not more than 1000 ppm of S.

Meanwhile, for the sake of comparison, commercially available cobalt oxide in fine powder form and lithium carbonate powders were mixed with the same manganese oxide as that used in Working Example 1 to be subsequently fired under the same condition as in the case of Example 1, thereby obtaining a lithium-manganese oxide complex of the same composition as that for Working Example 1, doped with 5% of Co (this is referred to as material for Comparative Example 1).

Thereafter, slurries composed of 85% of the respective materials, 8% of acetylene black, and 7% of PVDF (poly(vinylidene fluoride) were prepared by use of NMP (N-methyl-2-pyrrolidone) as a solvent, and the slurries were applied to aluminum foils, respectively, to be dried before press-forming, thereby obtaining cathode samples for evaluation of the respective lithium secondary cells.

The respective lithium secondary cells for use in the evaluation were coil-cell models of the 2032 type wherein the respective cathode samples were used for the respective cathodes thereof while a lithium foil was used for the respective opposite electrodes thereof, and for the respective electrolytes thereof, use was made of a solvent where the ratio of EC (ethylene carbonate) / DMC (dimethyl carbonate) was 1:1, in which LiPF_6 at 1 mole was dissolved.

Using the respective lithium secondary cells for the evaluation, the initial capacity, cycle characteristics, and safety thereof were examined, and the results of examinations are shown in Table 1.

As for the cycle characteristics, the capacity retention ratio after 100 cycles in operation at 55°C was examined.

Further as for safety, an oxygen elimination temperature was examined by carrying out a differential thermal analysis

(DSC) after electrochemically removing Li out of the cathode material. The oxygen elimination temperature refers to the temperature at which oxygen is eliminated when the temperature of the cathode material is raised, and needless to say, the higher the temperature, the higher the safety is.

Table 1

| Measurement Items | Measuring results of characteristics | |
|--------------------------|--------------------------------------|--------------------------------------|
| | the material for Example 1 | the material for compa. Example 1 |
| Initial capacity | 120 mA h/g | 115 mA h/g |
| Cycle characteristics | 91% | 82% |
| safety | 360°C | 354°C |

As is evident from the results shown in Table 1, it is apparent that with the method according to the invention, it is possible to stably produce a lithium-manganese oxide complex-based cathode material for a lithium secondary cell having excellent initial capacity, cycle characteristics and safety.

Example 2

First, lithium carbonate was dissolved in water to prepare an aqueous solution thereof and by blowing carbon dioxide in the former, 6 liters of an aqueous solution of lithium hydrogencarbonate at 0.35 mole/l was prepared.

Subsequently, 1 kg of commercially available cobalt oxide (2.5 µm in average grain size, 2.9 m²/g in specific surface area, and 2.5 g/cc in tap density) was suspended in the aqueous solution of lithium hydrogencarbonate and an aqueous solution of manganese sulfate at 0.18 mole/l was dripped in the former at a rate of 0.2 l/hr to undergo reaction at room temperature for a predetermined time, and to be subsequently washed in water, thereby obtaining cobalt oxide with the surface thereof coated with manganese carbonate.

With reference to the cobalt oxide obtained after the above-described processing, it was confirmed by observation with the SEM (scanning electron microscope) and the EPMA (electron beam probe microanalyzer) that the surface of the cobalt oxide was uniformly coated with the manganese carbonate, and the mole ratio of Co to Mn was 95:5.

Subsequently, after mixing lithium carbonate with the "cobalt oxide coated with a manganese carbonate" such that the ratio of Li/(Mn + Co) was 1.00, the obtained mixture was fired at 850°C in the atmosphere for 10 hrs, thereby obtaining a lithium-cobalt oxide complex (LiCoO_2) doped with 5% of Mn (this is referred to as material for Working Example 2).

The material obtained was 6 μm in average grain size, 1.4 m^2/g in specific surface area, and 2.2 g/cc in tap density. Further, the material was found to contain 500 ppm of Ca and 1500 ppm of S, which coincided with respective contents of impurities of commercially available cobalt oxide, indicating that there was no contamination occurring due to the reaction.

Meanwhile, for the sake of comparison, respective powders of commercially available cobalt oxide, manganese carbonate, and lithium carbonate were mixed with each other and subsequently fired under the same conditions as in Working Example 2, thereby producing a lithium-cobalt oxide complex of the same composition as that for Working Example 2, doped with 5% of Mn (this is referred to as material for Comparative Example 2).

Thereafter slurries composed of 85% of the respective materials, 8% of acetylene black, and 7% of PVDF (poly(vinylidene fluoride) were prepared by use of NMP (N-methyl-2-pyrrolidone) as a solvent, and the slurries were applied to aluminum foils, respectively, to be dried before press-forming, thereby obtaining cathode samples for evaluation of respective lithium secondary cells.

The respective lithium secondary cells for use in the evaluation were coil-cell models of the 2032 type wherein the respective cathode samples were used for the respective

cathodes thereof while a lithium foil was used for the respective opposite electrodes thereof, and for the respective electrolytes thereof, use was made of a solvent where the ratio of EC (ethylene carbonate) / DMC (dimethyl carbonate) was 1:1, in which LiPF₆ at 1 mole was dissolved.

Using the respective lithium secondary cells for the evaluation, the initial capacity, cycle characteristics, and safety thereof were examined, respectively, as with the case of Working Example 1, and the results of the examinations are shown in Table 2.

Table 2

| Measurement Items | Measuring results of characteristics | |
|--------------------------|--------------------------------------|--------------------------------------|
| | the material for Example 2 | the material for compa. Example 2 |
| Initial capacity | 145 mA h/g | 140 mA h/g |
| Cycle characteristics | 95% | 90% |
| safety | 230 °C | 225 °C |

As is also evident from the results shown in Table 2, it is apparent that with the method according to the invention, it is possible to stably produce a lithium-cobalt oxide complex-based cathode material for a lithium secondary cell having excellent initial capacity, cycle characteristics and safety.

Example 3

First, lithium carbonate was dissolved in water to prepare an aqueous solution thereof, and by blowing carbon dioxide in the former, 6 liters of an aqueous solution of lithium hydrogencarbonate at 0.35 mole/l was prepared.

Subsequently, 1 kg of commercially available nickel oxide (6 µm in average grain size, 2.0 m²/g in specific surface area, and 2.4 g/cc in tap density) was suspended in the aqueous solution of lithium hydrogencarbonate, and an aqueous solution

of cobalt sulfate at 0.20 mole/l was dripped in the former at a rate of 0.2 l/hr to undergo a reaction at room temperature for a predetermined time, and to be subsequently washed in water, thereby obtaining nickel oxide with the surface thereof coated with cobalt carbonate.

With reference to the nickel oxide obtained after the above-described processing, it was confirmed by observation with the SEM (scanning electron microscope) and the EPMA (electron beam probe microanalyzer) that the surface of the nickel oxide was uniformly coated with the cobalt carbonate, and the mole ratio of Ni to Co was 80:20.

Subsequently, after mixing lithium carbonate with the "nickel oxide coated with the cobalt carbonate" such that the ratio of Li/(Ni+Co) was 1.00, the obtained mixture was fired at 750°C in the atmosphere for 10 hrs, thereby obtaining a lithium-nickel oxide complex (LiNiO_2) doped with 20% of Co (this is referred to as material for Working Example 3).

The material obtained was 8 μm in average grain size, 2.2 m^2/g in specific surface area, and 2.1 g/cc in tap density.

Meanwhile, for the sake of comparison, respective powders of commercially available nickel oxide, cobalt carbonate, and lithium carbonate were mixed with each other and subsequently fired under the same conditions as Working Example 3, thereby producing a lithium-nickel oxide complex of the same composition as Working Example 3, doped with 20% of Co (this is referred to as material for Comparative Example 3).

Thereafter, slurries composed of 85% of the respective materials, 8% of acetylene black, and 7% of PVDF (poly(vinylidene fluoride) were prepared by use of NMP (N-methyl-2-pyrrolidone) as a solvent, and the slurries were applied to aluminum foils, respectively, to be dried before press-forming, thereby obtaining cathode samples for evaluation of respective lithium secondary cells.

The respective lithium secondary cells for use in the evaluation were coil-cell models of the 2032 type wherein the respective cathode samples were used for the respective

cathodes thereof while a lithium foil was used for the respective opposite electrodes thereof, and for the respective electrolytes thereof, use was made of a solvent where the ratio of EC (ethylene carbonate) / DMC (dimethyl carbonate) was 1:1, in which LiPF₆ at 1 mole was dissolved.

Using the respective lithium secondary cells for evaluation, the initial capacity, cycle characteristics, and safety thereof were examined, respectively, as with the case of Working Example 1, and the results of the examinations are shown in Table 3.

Table 3

| Measurement Items | Measuring results of characteristics | |
|--------------------------|--------------------------------------|--------------------------------------|
| | the material for Example 3 | the material for compa. Example 3 |
| Initial capacity | 185 mA h/g | 180 mA h/g |
| Cycle characteristics | 85% | 80% |
| Safety | 230 °C | 225 °C |

As is also evident from the results shown in Table 3, it is apparent that with the method according to the invention, it is possible to stably produce a lithium-nickel oxide complex-based cathode material for a lithium secondary cell having excellent initial capacity, cycle characteristics and safety.

Example 4

"Manganese oxide identical in powder property to the manganese oxide that was used in Example 1" was used as the raw material of the major component of a cathode material for a lithium secondary cell for the production of the cathode material, and 1 kg thereof was suspended in 6 liters of an aqueous solution of lithium hydrogencarbonate at 0.35 mole/l, obtained by blowing carbon dioxide in aqueous solution of lithium carbonate, prepared by dissolving lithium carbonate in

water. Subsequently, an aqueous solution of aluminum chloride at 0.20 mole/l was dripped in the former at a rate of 0.2 l/hr to undergo a reaction similar to the case of Example 1, thereby obtaining manganese oxide with the surface thereof coated with aluminum hydroxide.

With reference to the manganese oxide obtained after the above-described processing, it was confirmed by observation with the SEM (scanning electron microscope) and the EPMA (electron beam probe microanalyzer) that the surface of the manganese oxide was uniformly coated with aluminum hydroxide and the mole ratio of Mn to Al was 90:10.

Subsequently, after mixing lithium carbonate with the "manganese oxide coated with the aluminum hydroxide" such that the ratio of Li/(Mn+Al) was 0.55, the obtained mixture was fired at 750°C in the atmosphere for 10 hrs, thereby obtaining a lithium-manganese oxide complex (LiMn_2O_4) doped with 10% of Al (this is referred to as material for Working Example 4).

The obtained material had powder properties of 10 μm in average grain size, $0.8 \text{ m}^2/\text{g}$ in specific surface area, and 2.0 g/cc in tap density.

Meanwhile, for the sake of comparison, commercially available aluminum oxide in fine powder form, and lithium carbonate powders were mixed with the same manganese oxide that was used in Working Example 4 to be subsequently fired under the same conditions as in Working Example 4, thereby producing a lithium-manganese oxide complex of the same composition as that of Working Example 4, doped with 10% of Al (this is referred to as material for Comparative Example 4).

Thereafter, slurries composed of 85% of the respective materials, 8% of acetylene black, and 7% of PVDF (poly(vinylidene fluoride) were prepared by the use of NMP (N-methyl-2-pyrrolidone) as a solvent, and the slurries were applied to aluminum foils, respectively, to be dried before press-forming, thereby obtaining cathode samples for the evaluation of respective lithium secondary cells.

The respective lithium secondary cells for use in the evaluation were coil-cell models of the 2032 type wherein the respective cathode samples were used for the respective cathodes thereof while a lithium foil was used for the respective opposite electrodes thereof, and for the respective electrolytes thereof, use was made of a solvent where the ratio of EC (ethylene carbonate / DMC (dimethyl carbonate) was 1:1, in which LiPF₆ at 1 mole was dissolved.

Using the respective lithium secondary cells for the evaluation, the initial capacity, cycle characteristics, and safety thereof were examined, respectively, as with the case of Working Example 1, and the results of the examinations are shown in Table 4.

Table 4

| Measurement Items | Measuring results of characteristics | |
|--------------------------|--------------------------------------|--------------------------------------|
| | the material for Example 4 | the material for compa. Example 4 |
| Initial capacity | 110 mA h/g | 108 mA h/g |
| Cycle characteristics | 96% | 93% |
| Safety | 365 °C | 358 °C |

As is also evident from the results shown in Table 4, it is apparent that with the method according to the invention, it is possible to stably produce a lithium-manganese oxide complex-based cathode material for a lithium secondary cell having excellent initial capacity, cycle characteristics and safety.

Example 5

First, lithium carbonate was dissolved in water to prepare an aqueous solution thereof, and by blowing carbon dioxide in the former, 6 liters of an aqueous solution of lithium hydrogencarbonate at 0.35 mole/l was prepared.

Subsequently, 1 kg of commercially available cobalt oxide identical in powder properties to the cobalt oxide that was used in Example 2 was suspended in the aqueous solution of lithium hydrogencarbonate, and an aqueous solution of aluminum chloride at 0.20 mole/l was dripped in the former at a rate of 0.2 l/hr to undergo a reaction at room temperature for a predetermined time, thereby obtaining cobalt oxide with the surface thereof coated with aluminum hydroxide.

With reference to the cobalt oxide obtained after the above-described processing, it was confirmed by observation with the SEM (scanning electron microscope) and the EPMA (electron beam probe microanalyzer) that the surface of the cobalt oxide was uniformly coated with the aluminum hydroxide, and the mole ratio of Co to Al was 95:5.

Subsequently, after mixing lithium carbonate with the "cobalt oxide coated with the aluminum hydroxide" such that the ratio of Li/(Co+Al) was 1.00, the obtained mixture was fired at 850°C in the atmosphere for 10 hrs, thereby obtaining a lithium-cobalt oxide complex (LiCoO_2) doped with 5% of Al (this is referred to as material for Working Example 5).

The obtained material had powder properties of 5 μm in average grain size, 1.5 m^2/g in specific surface area, and 2.2 g/cc in tap density.

Meanwhile, for the sake of comparison, respective powders of commercially available cobalt oxide, aluminum oxide, and lithium carbonate were mixed with each other, and subsequently fired under the same conditions as in Working Example 5, thereby producing a lithium-cobalt oxide complex of the same composition as Working Example 5, doped with 5% of Al (this is referred to as material for Comparative Example 5).

Thereafter, slurries composed of 85% of the respective materials, 8% of acetylene black, and 7% of PVDF (poly(vinylidene fluoride) were prepared by the use of NMP (N-methyl-2-pyrrolidone) as a solvent, and the slurries were applied to aluminum foils, respectively, to be subsequently

dried before press forming, thereby obtaining cathode samples for the evaluation of respective lithium secondary cells.

The respective lithium secondary cells for use in the evaluation were coil-cell models of the 2032 type wherein the respective cathode samples were used for the respective cathodes thereof while a lithium foil was used for the respective opposite electrodes thereof, and for the respective electrolytes thereof, use was made of a solvent where the ratio of EC (ethylene carbonate) / DMC (dimethyl carbonate) was at 1:1, in which LiPF₆ at 1 mole was dissolved.

Using the respective lithium secondary cells for the evaluation, the initial capacity, cycle characteristics, and safety thereof were examined, respectively, as with the case of Working Example 1, and the results of the examinations are shown in Table 5.

Table 5

| Measurement Items | Measuring results of characteristics | |
|--------------------------|--------------------------------------|--------------------------------------|
| | the material for Example 5 | the material for compa. Example 5 |
| Initial capacity | 143 mA h/g | 138 mA h/g |
| Cycle characteristics | 93% | 90% |
| safety | 228 °C | 225 °C |

As is also evident from the results shown in Table 5, it is apparent that with the method according to the invention, it is possible to stably produce a lithium-cobalt oxide complex-based cathode material for a lithium secondary cell having excellent initial capacity, cycle characteristics and safety.

Example 6

First, lithium carbonate was dissolved in water to prepare an aqueous solution thereof, and by blowing carbon

dioxide in the former, 6 liters of an aqueous solution of lithium hydrogencarbonate at 0.35 mole/l was prepared.

Subsequently, 1 kg of the same commercially available nickel oxide that was used in Example 3 was suspended in the aqueous solution of lithium hydrogencarbonate, and an aqueous solution of manganese sulfate and cobalt sulfate, at 0.20 mole/l, respectively, was dripped in the former at a rate of 0.2 l/hr to undergo a reaction at room temperature for a predetermined time, thereby obtaining nickel oxide with the surface thereof coated with manganese carbonate and cobalt carbonate.

With reference to the nickel oxide obtained after the above-described processing, it was confirmed by observation with the SEM (scanning electron microscope) and the EPMA (electron beam probe microanalyzer) that the surface of the nickel oxide was uniformly coated with the carbonates of the respective metals, and the mole ratio of Ni:Co:Mn was 60:20:20.

Subsequently, after mixing lithium carbonate with the "nickel oxide coated with the carbonates of the respective metals" such that the ratio of Li/(Ni+Co+Mn) was 1.10, the obtained mixture was fired at 850°C in the atmosphere for 10 hrs, thereby obtaining a lithium-nickel oxide complex (LiNiO_2) doped with Co and Mn (this is referred to as material for Working Example 6).

The material obtained was 6 μm in average grain size, 1.4 m^2/g in specific surface area, and 2.0 g/cc in tap density.

Meanwhile, for the sake of comparison, respective powders of commercially available nickel oxide, manganese carbonate, cobalt carbonate, and lithium carbonate were mixed with each other and subsequently fired under the same conditions as that for Working Example 6, thereby producing a lithium-nickel oxide complex of the same composition as that for Working Example 6, doped with Co and Mn (this is referred to as material for Comparative Example 6).

Thereafter, slurries composed of 85% of the respective materials, 8% of acetylene black, and 7% of PVDF

(poly(vinylidene fluoride) were pared by the use of NMP (N-methyl-2-pyrrolidone as a solvent), and the slurries were applied to aluminum foils, respectively, to be dried before press forming, thereby obtaining cathode samples for the evaluation of respective lithium secondary cells.

The respective lithium secondary cells for use in the evaluation were coil-cell models of the 2032 type wherein the respective cathode samples were used for the respective cathodes thereof while a lithium foil was used for the respective opposite electrodes thereof, and for the respective electrolytes thereof, use was made of a solvent where the ratio of EC (ethylene carbonate) / DMC (dimethyl carbonate) was 1:1, in which LiPF₆ at 1 mole was dissolved.

Using the respective lithium secondary cells for the evaluation, the initial capacity, cycle characteristics, and safety thereof were examined, respectively, as with the case of Working Example 1, and the results of the examinations are shown in Table 6.

Table 6

| Measurement Items | Measuring results of characteristics | |
|--------------------------|--------------------------------------|--------------------------------------|
| | the material for Example 6 | the material for compa. Example 6 |
| Initial capacity | 170 mA h/g | 165 mA h/g |
| Cycle characteristics | 85% | 78% |
| safety | 260°C | 255°C |

As is also evident from the results shown in Table 6, it is apparent that with the method according to the invention, it is possible to stably produce a lithium-nickel oxide complex-based cathode material for a lithium secondary cell having excellent initial capacity, cycle characteristics and safety.

Example 7

"Manganese carbonate produced by blowing carbon dioxide into aqueous ammonia of metallic manganese in accordance with the method disclosed in JP-A 2000-281351 as previously described" was used as the raw material of the major component of a cathode material for a lithium secondary cell, for production of the cathode material.

Subsequently, 1 kg of the manganese carbonate described above was suspended in 6 liters of an aqueous solution of lithium hydrogencarbonate at 0.3 mole/l, and an aqueous solution of nickel chloride at 0.22 mole/l was dripped in the former at a rate of 0.2 l/hr, thereby obtaining manganese carbonate with the surface thereof coated with nickel carbonate.

With reference to the manganese carbonate obtained after the above-described processing, it was confirmed by observation with the SEM (scanning electron microscope) and the EPMA (electron beam probe microanalyzer) that the surface of the manganese carbonate was uniformly coated with the nickel carbonate, and the mole ratio of Mn to Ni was 49:51.

Subsequently, after mixing lithium carbonate with the "manganese carbonate coated with the nickel carbonate" such that the ratio of $\text{Li}/(\text{Mn}+\text{Ni})$ was 1.00, the obtained mixture was fired at 900°C in the atmosphere for 10 hrs, thereby obtaining a lithium-manganese-nickel oxide complex (this is referred to as material for Working Example 7).

The obtained material was 8 μm in average grain size 1.4 m^2/g in specific surface area, and 2.1 g/cc in tap density.

Meanwhile, for the sake of comparison, respective powders of nickel carbonate and lithium carbonate were mixed with powders of the same manganese carbonate used in Working Example 7 to be subsequently fired under the same conditions as in Working Example 7, thereby obtaining a lithium-manganese-nickel oxide complex of the same composition as that for Working Example 7 (this is referred to as material for Comparative Example 7).

Thereafter, slurries composed of 85% of the respective materials, 8% of acetylene black, and 7% of PVDF (poly(vinylidene fluoride) were prepared by using NMP (N-methyl-2-pyrrolidone) as a solvent, and the slurries were applied to aluminum foils, respectively, to be dried before press-forming, thereby obtaining cathode samples for the evaluation of the respective lithium secondary cells.

The respective lithium secondary cells for use in the elevation were coil-cell models of the 2032 type wherein the respective cathode samples were used for the respective cathodes thereof while a lithium foil was used for the respective opposite electrodes thereof, and for the respective electrolytes thereof, use was made of a solvent where the ratio of EC (ethylene carbonate) / DMC (dimethyl carbonate) was 1:1, in which LiPF₆ at 1 mole was dissolved.

Using the respective lithium secondary cells for the evaluation, the initial capacity, cycle characteristics, and safety thereof were examined as with the case of Example 1, and the results of the examinations are shown in Table 7.

Table 7

| Measurement Items | Measuring results of characteristics | |
|--------------------------|--------------------------------------|--------------------------------------|
| | the material for Example 7 | the material for compa. Example 7 |
| Initial capacity | 160 mA h/g | 155 mA h/g |
| Cycle characteristics | 80% | 76% |
| safety | 280°C | 274°C |

As is also evident from the results shown in Table 7, it is apparent that with the method according to the invention, it is possible to stably produce a lithium-manganese-nickel oxide complex-based cathode material for a lithium secondary cell having excellent initial capacity, cycle characteristics and safety.

INDUSTRIAL APPLICABILITY

The invention can provide a cathode material for a lithium secondary cell with which it is possible to manufacture a lithium secondary cell having excellent initial capacity, cycle characteristics and safety.